Performance of DC Motor Supplied From Single Phase AC-DC Rectifier

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Abstract

In the last decades, considerable advancements have been made in the power electronics industry. The adjustable speed drive is very important for the control of motor speed, because many products can be handled, transferred and easily controlled. This paper discusses the performance of dc motor speed, field flux and loading on the ratio between input r.m.s armature current and average value in a separately exited dc motor fed from single-phase ac to dc rectifier. Also, computer simulation program was developed to predict motor performance, for the single-phase half wave rectifier. The out put of simulation shows a good correlation with the experimental results.

Keywords: DC-motor, Electronic Drive, Voltage and Current Form Factor

1 - Introduction

In the last decades, considerable advancements have been made in the power electronics industry. The adjustable speed drive is very important for the control of motor speed, because many products can be handled, transferred and easily controlled [1,2]. A method of control is mainly decided by the nature of the load. Some loads require very wide speed range while others require limited one. This implies that before deciding a certain control scheme, load requirements should be studied, for example electric train and cars need wide range of speed while lathes needed limited speed range[3,4,5]. The Root Mean Squares (r.m.s) values of current and voltage are responsible for copper losses while average values are responsible for torque produced. The accurate prediction of the performance of dc motors can be determined by accurate evaluation of its parameters. A number of tests have been carried out such as open and short circuit to estimate the parameters of the field and armature circuit, the iron and mechanical losses, the speed voltage coefficient and rotor moment of inertia. This paper discusses the performance of dc motor speed, field flux and loading on the ratio between input r.m.s armature current and average value in a separately exited dc motor fed from single-phase ac to dc rectifier. It was found that the performance of the dc motor in case of single-phase full wave rectifier is better than the case of single phase half-wave rectifier because the armature current is more continuous than for the case of half-wave single phase. Moreover, computer simulation program was developed to predict motor performance, for the single-phase half wave rectifier. The simulation is based on a set of non-linear equations which define the behavior of the rectifier and the dc motor during the time of conduction and non-conduction of the diode, and during load variation from no load to full load on the dc motor. The output of simulation shows a good correlation with the experimental results. Also the paper discusses the armature voltage and current form factor for various step values of dc motor load condition from no load to full load. The form factor has been taken as measure of motor losses in relation to its output torque. It was found that the armature voltage and current form factor curves vary with the variation of ac supply voltage and with the values of load of dc motor.

2- Motor Parameters Evaluation

The accurate prediction of dc machines performance when fed from a rectified ac supply can be achieved by accurate evaluation of its main parameters. Therefore, number of tests has been carried out to estimate these parameters. The parameters measured are speed voltage coefficient Kv armature and field resistances and inductances, iron and mechanical losses and rotor moment of inertia. The results are as follow: Armature circuit r_a = 6.25 Ω, L_a = 0.03582 H, Field circuit, r_f = 625 Ω, L_f = 51.762 H, T_f = 0.0828 sec. The dc motor losses are: Mechanical Losses = 28 watt, at n = 1500 r.p.m , Mechanical Losses = 41 watt, at n = 1800 r.p.m , Iron loss = 14 watt, at V_a = 110 V and n = 1500 rpm , Iron loss = 9 watt at V_a = 110 V and n = 1800 rpm , J= Inertia of rotor = 0.256 $kg.m^2$

3 - Operation From Half Wave Single Phase Rectifier Supply

The dc motor can be operated from single phase ac supply via a half-wave rectifier system as shown in Fig. (1). Assuming constant value of field current and hence flux and constant rotor speed of ω_r , then operation of diode will be decided by the relative magnitudes of V_s , back emf E and voltage drop across r_a and L_a. During diode conduction the supply voltage is given by the following equation :

$$Vs = Vm * \sin \omega t = r_a i_a + L_a (di_a/dt)+E \quad \text{.........(1)}$$

Where $E = K_v\phi\omega_r$ .... (2)

Moreover, electro-magnetic torque is given by $Te = Kv\ \phi\ i_a$ ....(3)

During the steady state analysis, the armature current will flow in discrete pulses. The duration of these pulses is determined by the value of E with respect to instantaneous value of V_s . Because V_s is higher than E the diode will start conducting but will not cut off as soon as V_s is lower than E, since energy stored in armature inductance must be released, as shown in Fig. (2). Therefore, the period of conduction is mainly determined by the value of E with respect to V_{max} and the value of L_a.

For half-wave case, because the current flows in pulses, the r.m.s is higher than the average values. During steady-state, and when diode D conducts, (V_D = 0) , the supply voltage V_s is given by equation (1).

Integrating both sides with respect to ωt for $\alpha < t < \beta$, as shown in Fig. (2)

$$0 = (Vm/z) \sin (\alpha+\Upsilon-\phi) - (E/z \cos\phi) + [(E/z \cos\phi) - (Vm/z) \sin (\alpha -\phi)] \times e^{(ra/xa)\,(\alpha - (\alpha+\Upsilon))}$$

Solution for $(\beta-\Upsilon)$ can be achieved using one of the known iterative techniques.

4 - Motor Performance

The motor performance is studied for different no-load and load conditions. During the no-load operation of the motor, the current waveform is not continuous. This discontinuity in current waveform will make the value of I rms is greater than I av. The average torque developed by the motor is function of i_{av}; while copper-loss is proportional to $(I_{rms})^2$. Comparison between motor performance when fed from pure dc supply and when fed from half wave rectified supply can be then achieved by determining the Form Factor of the Current (FFI). The FF is defined as the ratio of the rms to the average value. On no load the effect of field flux and motor speed on current form factor is studied for various field current. The field current (I_f) is maintained at constant values of 0.1A, 0.15A, 0.2A and 0.23A. For each value of field current the speed of motor is varied by varying applied armature voltage. The results are plotted in figures (3) and (4). It is clear from figure 3 that the increase of field current will increase the FFI. Figure 4 shows that an increase of no-load speed with fixed field current will cause an initial decrease in armature Voltage Form Factor (FFV) which is followed by an increase when the speed (n) is greater than 900 rpm. Generally speaking, FFV is approximately equal to one since armature voltage receives a contribution from supply voltage only during the short period of diode conduction.

The loading the motor have effects on the form factor of the input current. The variation of FFI and FFV for loaded motor case are shown in figures 5 an6 respectively. The following points could be concluded. (1) For constant load torque and field excitation an increase in motor speed leads to an increase in the value of FFI which means that the period of current conduction has decreased. (2) Increasing load torque with fixed values of n and I_f yielded decrease in the value of FFI which means that the average value of armature current and the applied voltage must increase, therefore the period of conduction will increase. (3) For fixed value of speed and load torque an increase in I_f leads to decrease in FFI. Moreover an increase in motor speed leads to decrease in FFV. Also an increase in load torque resulted in an increase in the value of FFV.

Figure 1 shows a Free Wheeling Diode (FWD). The FWD serves as a current path for reactive energy in armature inductance during main diode non conduction. The motor performance, when the FWD is connected, for the no-load and loaded cases are shown in figures 7 to 10. During the no-load the FWD will operate if the armature inductance is high. This is checked by inserting series inductance of 50 mH and 200 mH in the armature circuit. Figures 7 and 8 show the variation of FFI and FFV respectively. Figures 9 and 10 show the variation of FFI and FFV respectively for loaded conditions. It is clear from figures 9 and 10 that the FFI and FFV decrease for the same torque and field current, when the armature inductance increases.

5 - Single Phase Full Wave Rectifier Supply

The motor performance with full-wave rectification is better than half-wave because the armature current is more continuous than the half-wave rectification. The percentage of conduction to nonconduction periods will increase, resulting in a better current form factor (FFI). Figure 11 represents the dc motor full-wave rectifier circuit.

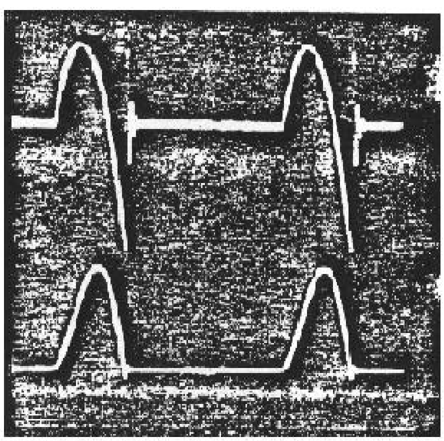
The operation of dc motor on no-load and load conditions are given in figures 12 to 15. It is clear form figures 12 and 13 that for a decrease of field current, the FFI will decrease and FFV will increase respectively. Also an increase in motor no-load speed led to an increase in FFI. Regarding FFV it showed a V-curve relationship with speed. It is clear from figure 14 and 15 that when the load torque increases the FFI decreases and the FFV increases respectively.

6 - Simulation of DC Motor Supplied from Half Wave Rectifier

The motor performance when supplied from half-wave rectifier is compared with the simulation analysis. The numerical analysis techniques are used to solve the set of non-linear equation of the motor. The analysis for dc motor operation is derived by assuming constant back e.m.f (E) which is developed by the motor. However, such a situation occurs only with motors having very high inertia. In reality, motors do have limited values of inertia, so back e.m.f will not be constant. Consequently, detailed analysis has been developed taking such effect into consideration. The output of the simulation for no-load and load conditions are shown in figure 16 and 17 respectively. It is clear from the figures that a good correlation exist between the simulation and the measurement.

7 - Conclusion

The performance of the dc motor which is supplied from half and full wave rectifier is studied for the no-load and load conditions. It was shown that the FFI and FFV of wave shapes of the dc motor are related to the no-load and load conditions and the half and full wave of the supply system. The full-wave rectifier supply is more suitable for the motor as compared to half-wave. Generally speaking it was observed that, in the drive systems investigated in this study, an increase in field current is accompanied by a consequent increase in FFI. The use of free wheeling diodes is recommended when instantaneous values of motor voltage reach negative levels. Such a situation arises when armature inductance is of high value. Theoretical analysis showed good correlation between predicted and experimentally obtained current and voltage waveforms.



(v)

(i)

This picture, of voltage(v) and current(i), shows good correlation with the computer simulation output which are given in figure 16 (a) and (b) respectively.

8 - References

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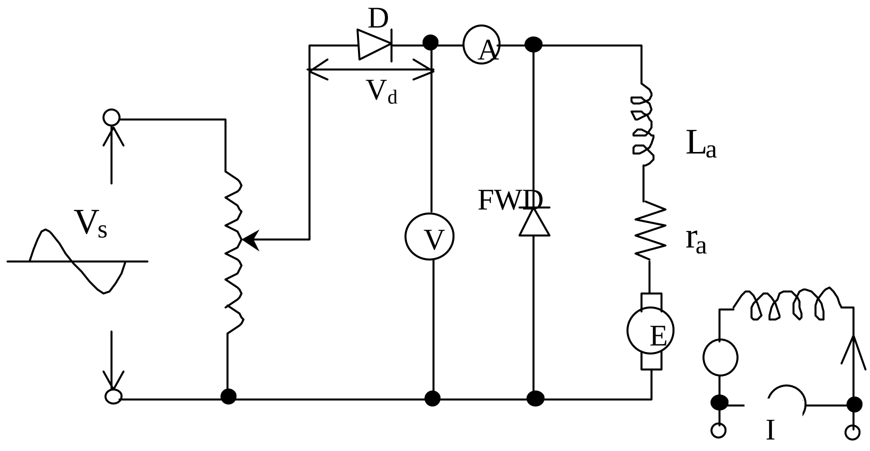


Fig. 1. Single-phase half wave rectifier supply to DC Motor

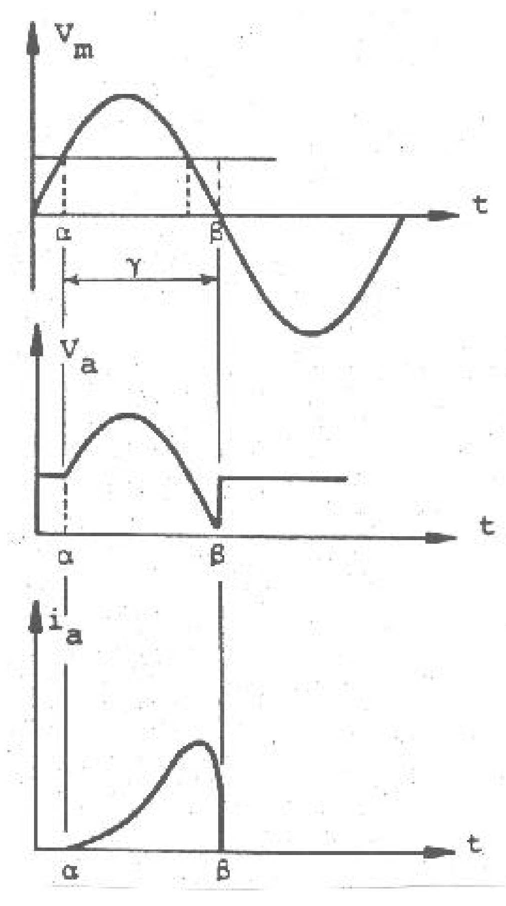


Fig. 2- Relation between delay, conduction and extinction angles of ac supply system.

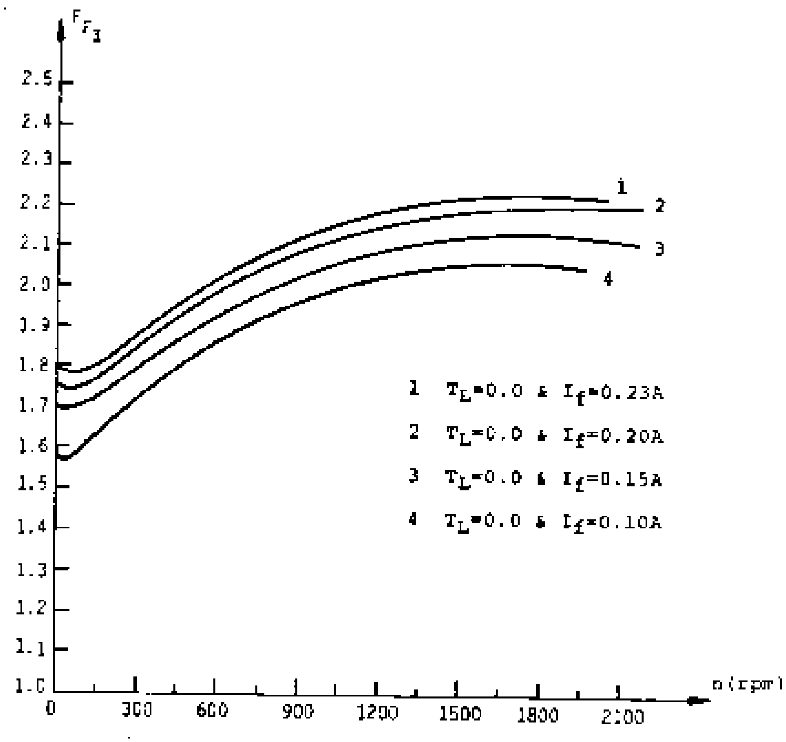


Fig 3

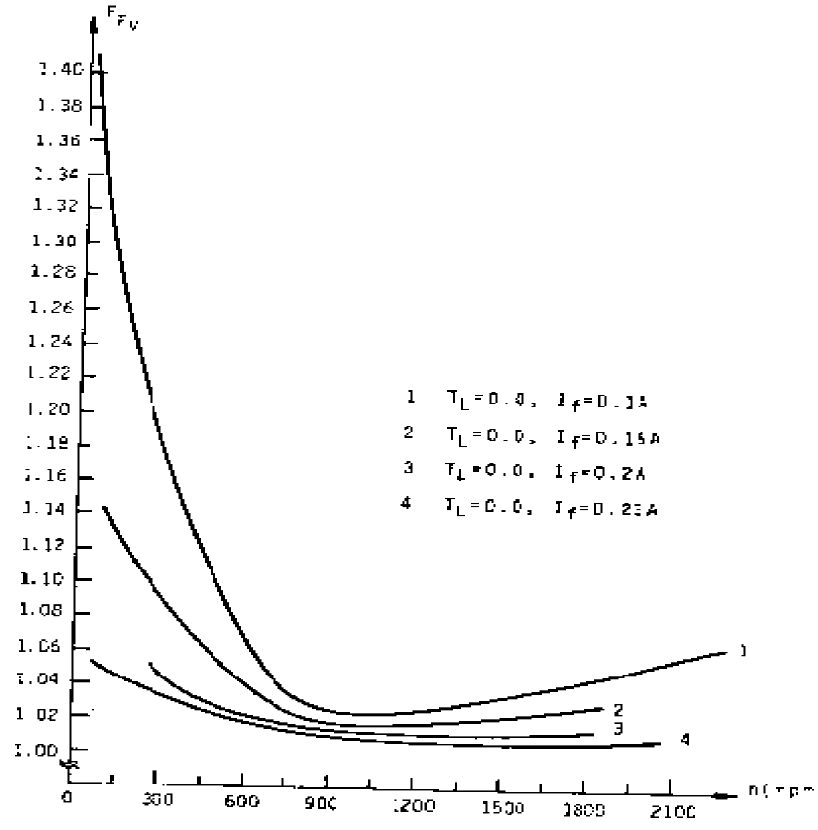
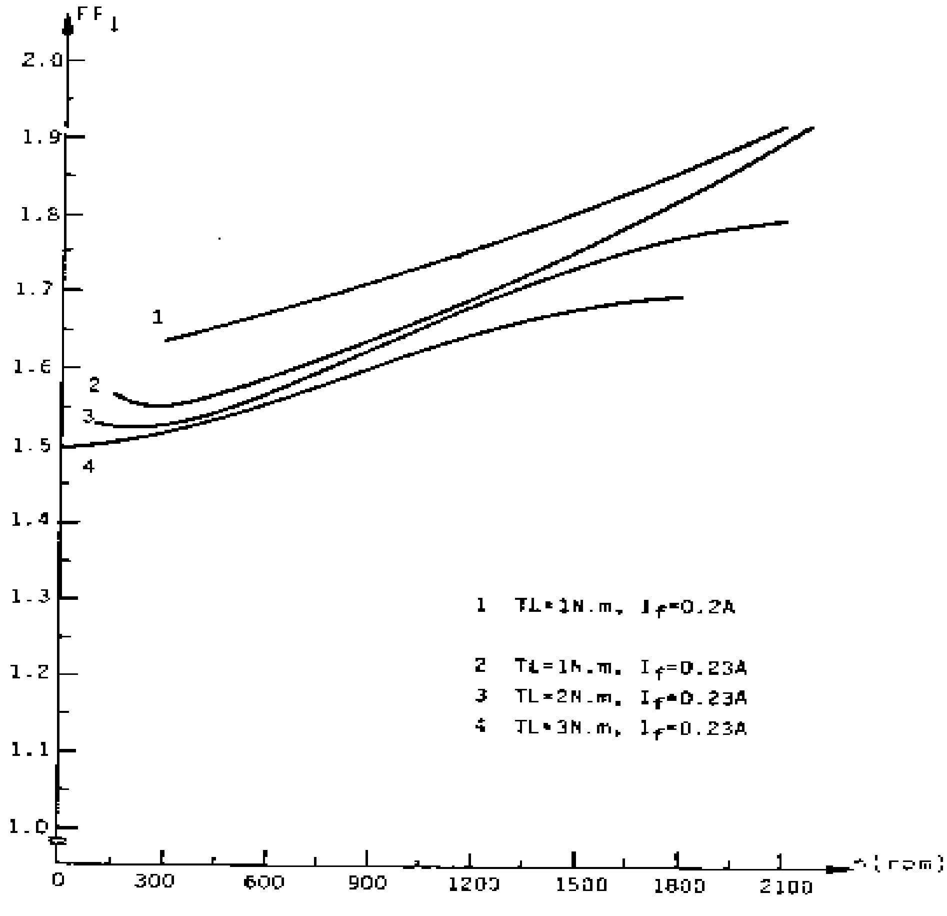


Fig 4

Fig. 3. Variation of armature current form factor versus no-load speed at different values of I_f

Fig. 4. Variation of armature voltage form factor versus no-load speed at different values of I_f



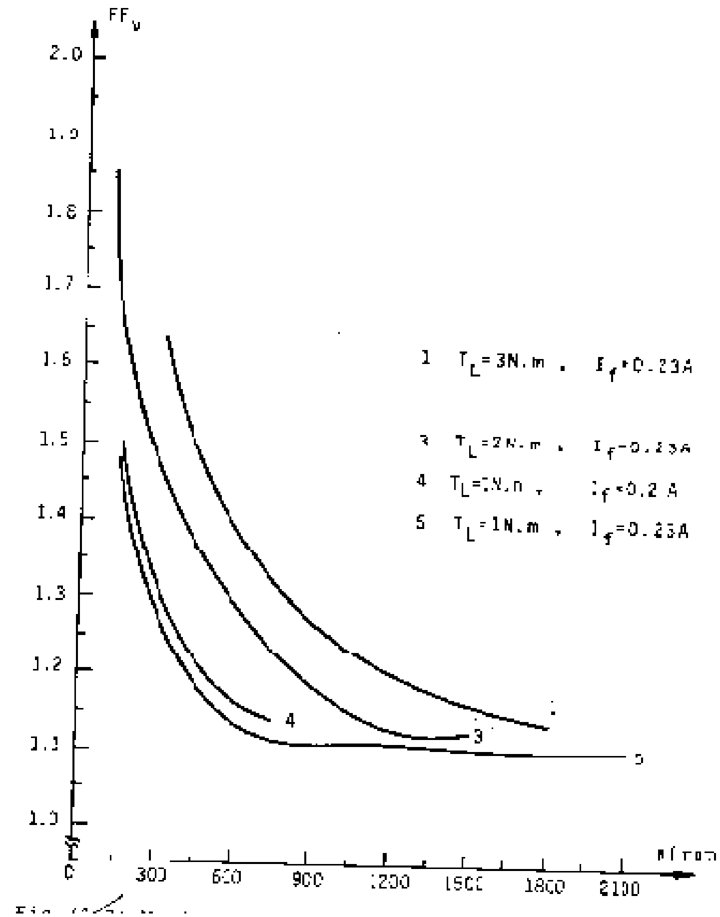


Fig 5

Fig 6

Fig. 5- Variation of armature current form factor versus speed at different values of load torque and field current.
Fig. 6- Variation of armature voltage form factor versus speed at different values of load and field current.

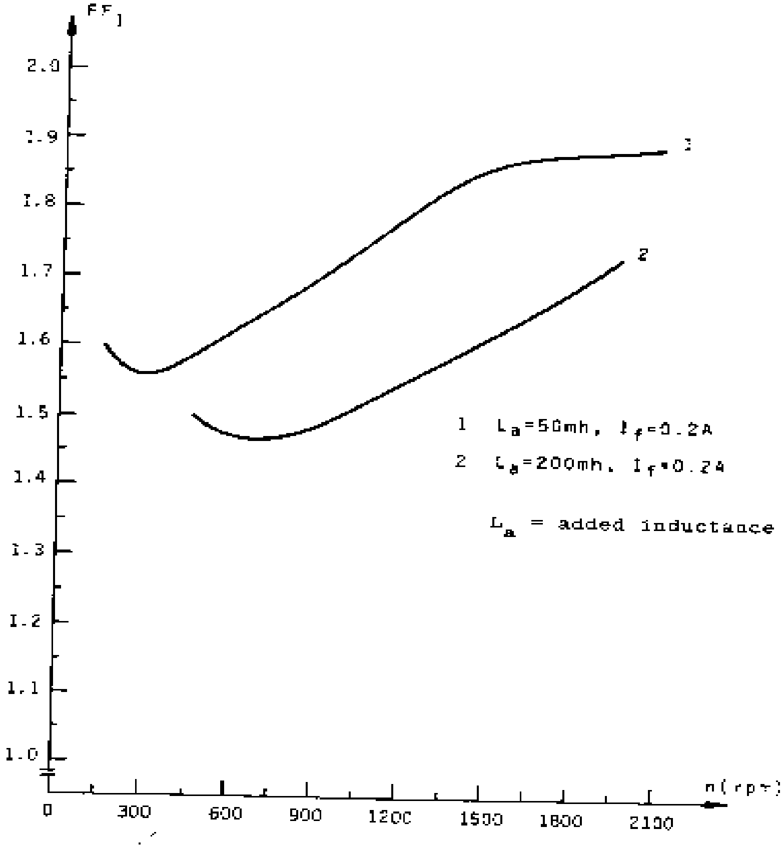


Fig 7

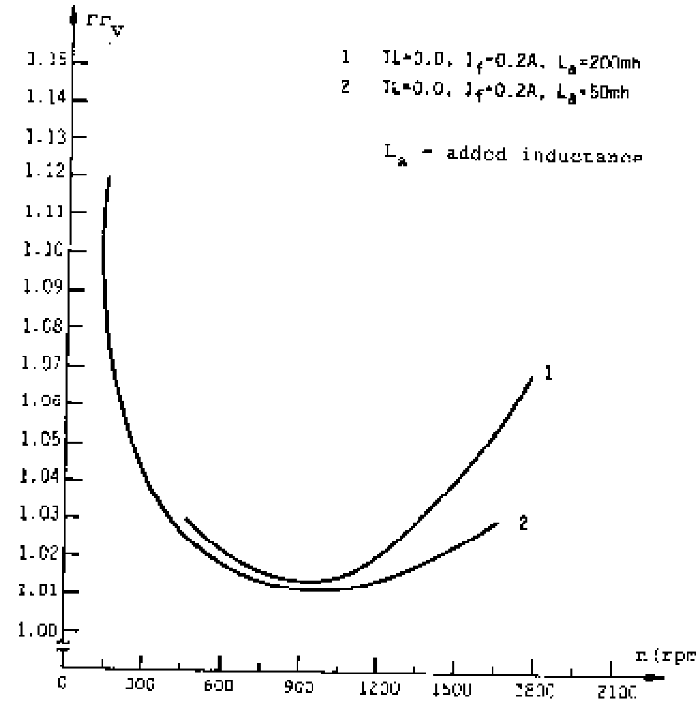


Fig 8

Fig. 7-Variation of armature current form factor versus no-load speed at different values of added inductance and same I_f “FWD-no-lad”

Fig. 8-Variation of armature voltage form factor versus no-load speed at different values of added inductance and same I_f “FWD-no-load”

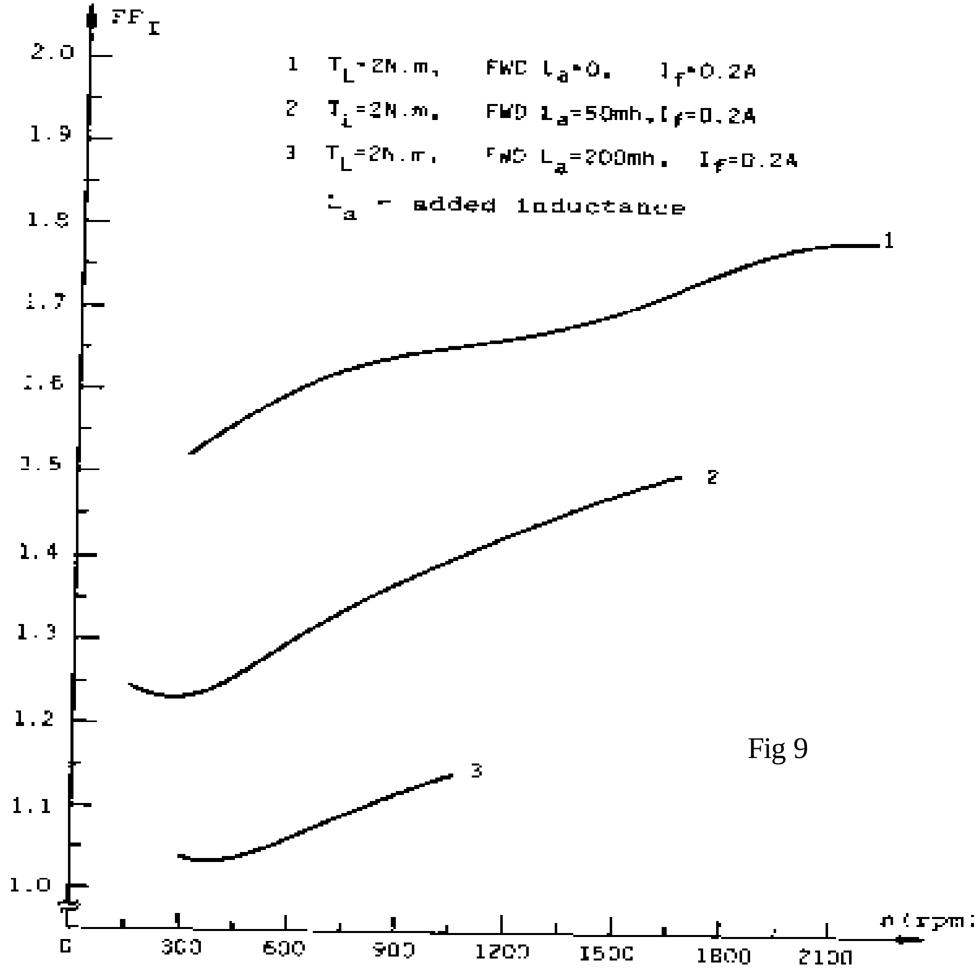


Fig 9

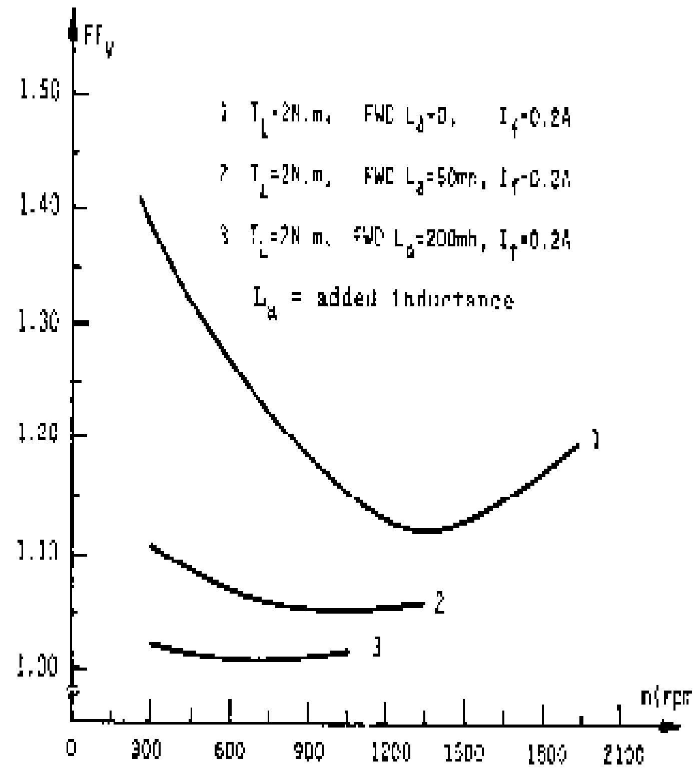


Fig 10

Fig. 9 -Variation of armature current from factor versus load speed at different values of added inductance and same I_f “FWD, loaded”
Fig. 10 -Variation of armature voltage from factor versus load speed at different values of added inductance and same I_f “FWD, loaded”

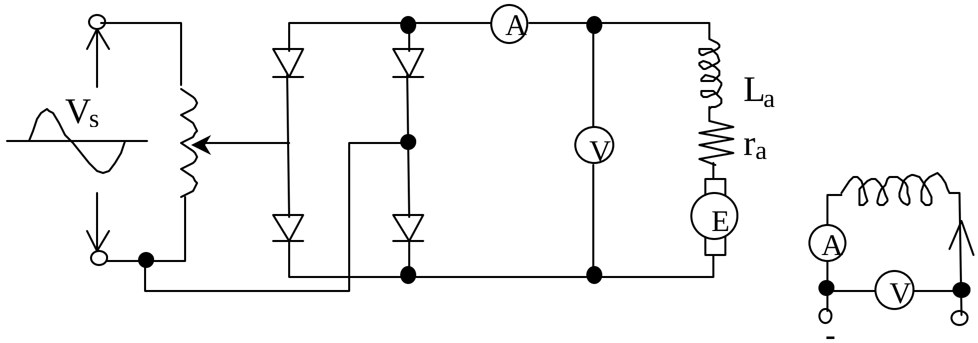


Fig. 11- Single-phase full wave rectifier supply to DC Motor

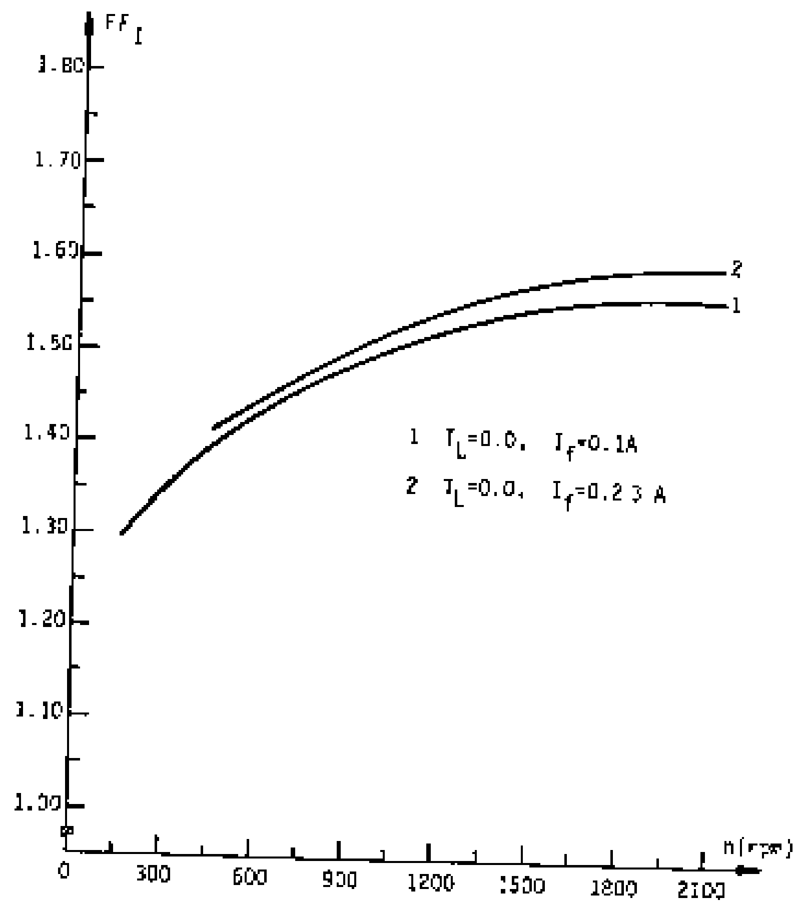


Fig. 12-Variation of motor current form factor versus speed at different values of field excitation.

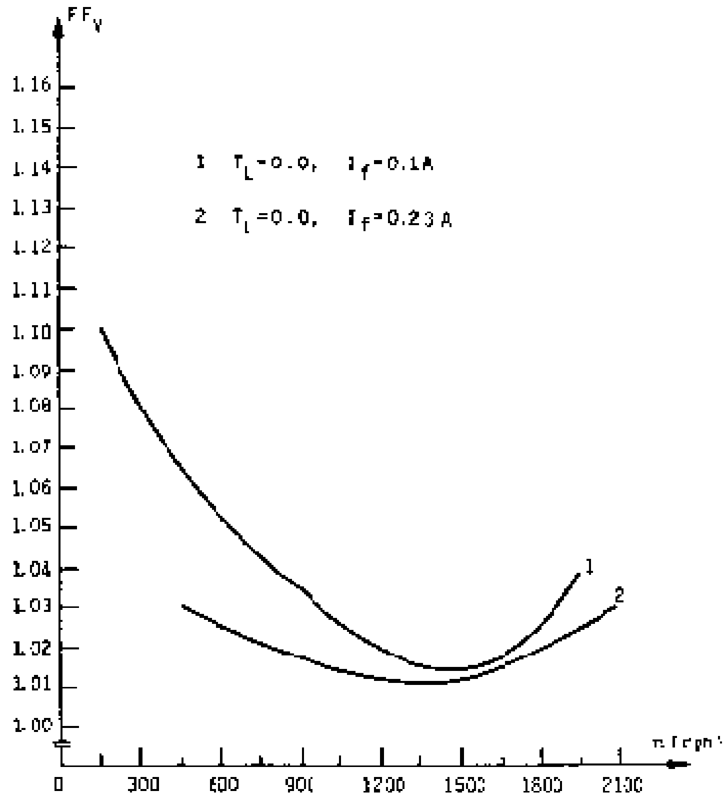


Fig 13

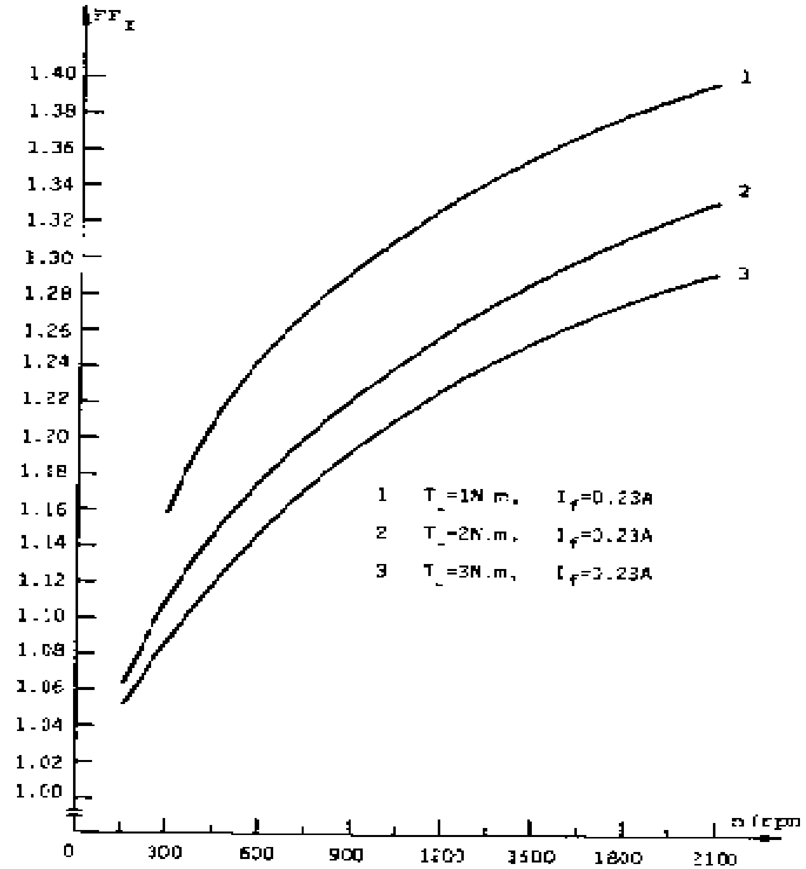


Fig 14

Fig. 13- Variation of motor voltage form factor versus speed at different values of field excitation.
Fig. 14 -Variation of armature current form factor versus motor speed at different values of field current

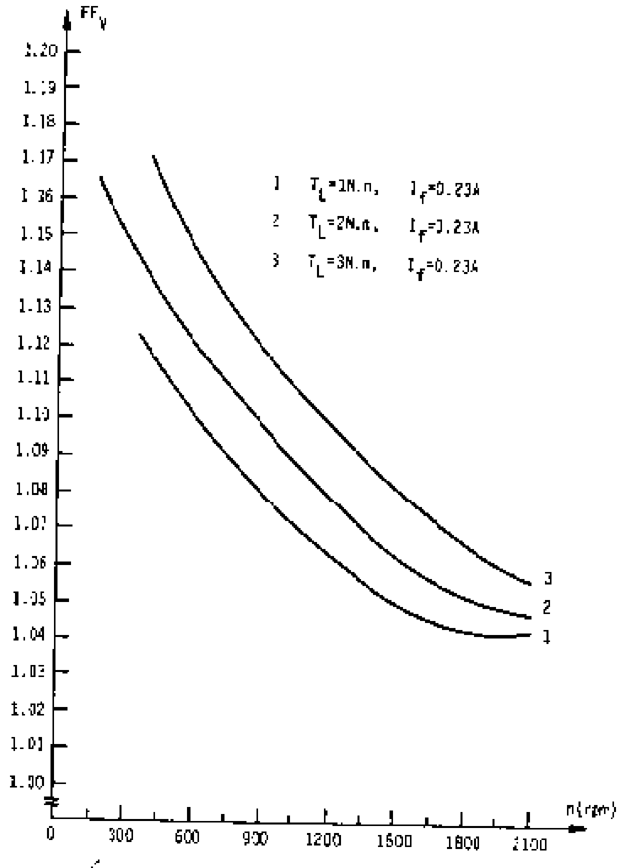


Fig15

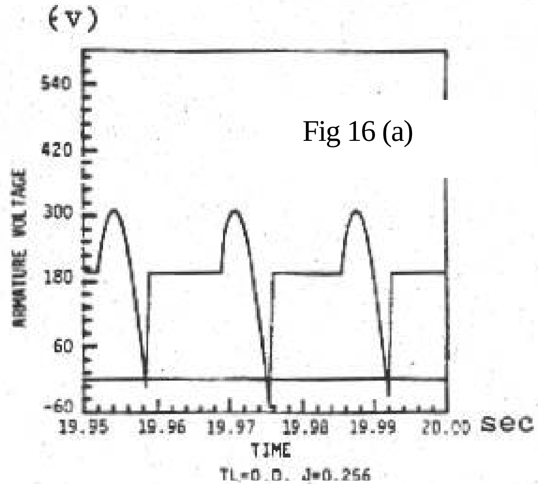


Fig 16 (a)

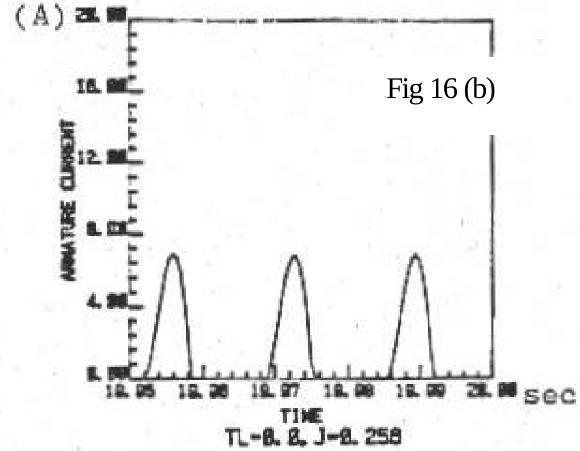


Fig 16 (b)

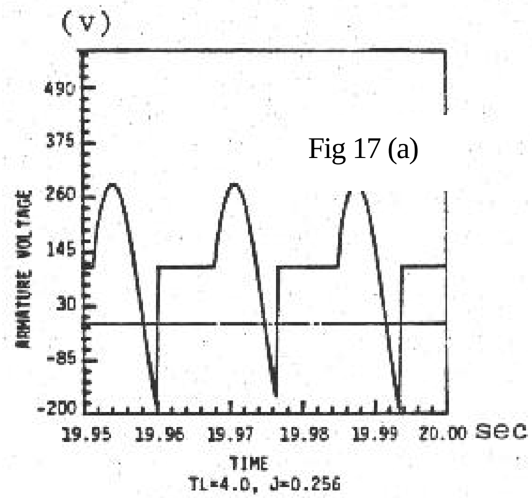


Fig 17 (a)

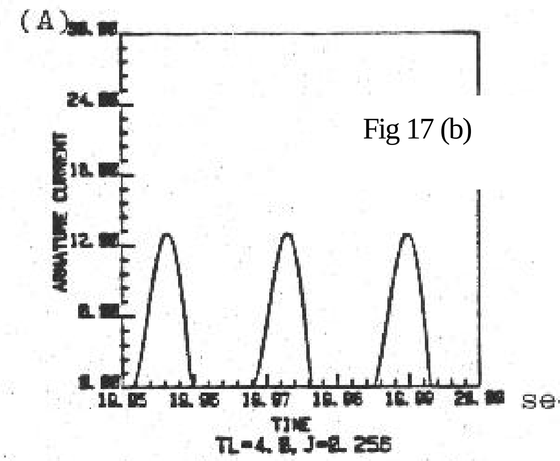


Fig 17 (b)

Fig 15 - Variation of armature voltage form factor versus motor speed at different values of field current.
Fig 16 (a) and (b) - Half wave supply simulation result of dc motor armature voltage and current at no load.
Fig 17 (a) and (b) - Half wave supply simulation result of dc motor armature voltage and current at 4.0Nm.